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ACOUSTIC AND PERCEPTUAL ANALYSIS OF VOCAL REGISTERS IN CHILDREN

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ABSTRACT

According to Hirano, Kurita and Nakashima (1983) the vocal fold structure changes continuously from earliest childhood to late adolescence. During puberty the elastic fibers are differentiated from the deeper collagenous fibers. These changes can be assumed to affect the vocal register function. The pitches at which register transitions occurred were identified perceptually in recordings of 15 ten-year-old children who sustained vowels at different pitches throughout their range. In normal voices two register transitions were observed, one at 466 Hz and one at 831 Hz mean fundamental frequency, or about 25% higher than in adult voices. Children with functional or physiological voice deviations exhibited only one transition at a mean frequency of 415 Hz.

INTRODUCTION

Vocal register is a highly relevant aspect of the singing voice, but its nature has remained unclear in the sense that many terms and definitions exist. Register has been defined as a "group of like sounds or tone qualities whose origins can be traced to a special kind of mechanical (muscular) action" (Reid, 1983, p 296). Thus the register phenomenon is assumed to be confined to the vocal fold vibration mechanism, excluding the relevance of vocal tract resonances.

However, based on experience with a theoretical model of the voice organ, Titze (1988) suggested that resonance is relevant to the register phenomenon. According to his theory, register boundaries occur when sub- or supraglottal resonances return significant reflections of the glottal pulses to the glottis in an unfavorable phase of their vibration. This means that the phenomenon of vocal register is dependent on the resonatory systems in the trachea and vocal tract as well as on the vocal fold mechanism. Also, the fundamental frequencies at which register transitions occur can be expected to differ depending on tracheal dimensions.

According to Hirano, Kurita and Nakashima (1983) the mechanical properties of the vocal folds change continuously during growth up to about 20 years of age. In infants, the vocal folds are 2 - 3 mm long, the membranous part being 1.3 - 2.0 mm and the lamina propria portion of the vocal fold is thick and not layered. The differentiation of the various layers of the lamina propria continues through puberty, thus separating it into three basic layers - the looser superficial layer, the intermediate elastic fibers and the deeper layer of collagenous fibers. Obviously, these changes can be assumed to affect vocal register function.

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In an earlier study of children's voices, a perceptual evaluation was carried out by a panel of seven voice expert listeners (Sederholm et al., 1993). The listeners rated the speaking voices of 58 10-year-old children who had been recorded on two separate occasions. The voices were rated along 15 voice parameters each of which was represented by a visual analogue (continuous) scale on a rating form. Among these parameters *voice breaks*, closely related to vocal registers, received few responses and was the only parameter which failed to reach a significant inter-judge reliability. In the rating form, *register* was included as a categorical scale, represented by the traditional terms chest and falsetto. "Normal child register" was offered as another option, which was widely preferred by the panel. This supports the assumption that childrens´ voices exhibit registers which are different from those of adult voices. However, a lack of experience with the particularities of childrens´ voices among our listeners as well as a lack of appropriate terminology for child voice registers may also have contributed to the results.

Register phenomena in childrens´ voices was observed in Voice Range Profiles (VRP), or phonetograms, by Pedersen et al. (1984). A VRP registration displays the sound pressure level in two contours representing softest and loudest possible phonation throughout the total pitch range. Pedersen et al. observed that register transitions tended to correspond with discontinuities exceeding 5 dB in the VRP contours. Klingholz and Martin (1983) proposed a method to describe the VRP contours by an "algorithm for the calculation of second-order curves". The method yields ellipses with characteristic slopes the intersection of which were assumed to reflect register transitions. Another method is described by Klingholz et al. (1985), where they analysed different aspects of contour discontinuities and their possible relation to register transitions.

As our study of 58 childrens´ voices included VRP analysis, a perceptual evaluation as well as a laryngeal examination, our material seemed particularly appropriate for investigating the relationships between VRP and child voice register (McAllister et al., 1993). The purpose of the present investigation was to analyse the occurrence of register transitions and examine their relations to the VRP contours.

SUBJECTS

Included in the present investigation were 15 children, 9 boys and 6 girls, selected from the original group of 58. They represented different diagnoses - chronic hoarseness, glottal chinks, vocal nodules, mutational voices plus controls with no perceptual or physiological voice deviation. The children had no special training in singing apart from the music education in school. Data on vocal fold status were available from a laryngoscopic examination carried out by the phoniatrician Patricia Gramming.

METHOD

Using a Sony ECM-55B microphone the VRP recordings were made on a Sony TCD-D1 (pitch range) digital audio tape recorder in a sound treated room (532x285x270cm) with an ambient noise level not exceeding 40 dB above 125 Hz. The microphone distance was approximately 30 cm. The subjects were asked to sing at each specific pitch on the vowel (a). A synthesiser, CASIO SA-20, was used for providing reference pitches. Whenever required, the pitches were also sung by the experimenter. In some cases it was necessary for the experimenter to sing together with the child and then let the child continue alone. The voice range profiles were determined following the procedure recommended by the Union of European Phoniatricians (Schutte and Seidner, 1983), although a flat frequency curve was preferred for the SPL measurement, as suggested by Gramming and Sundberg (1988).

Five judges identified register transitions from an audio tape where the tones pertaining to the upper and lower contours of each child´s VRP had been arranged in ascending pitch order. To establish intrajudge reliability, five voices were duplicated. These replications appeared at random on the test tape. The order of presentation of the voices was randomised for each listener individually.

The judges marked the location of the perceived transitions on a form where each tone was represented by a number which was also given on the tape. All judges had extensive experience with childrens´ voices; one was a children choir leader, three were singing teachers, and one was a speech pathologist and singer.

RESULTS

The interjudge reliability as determined by Cronbach's alpha was satisfactory, see Table 1. The low alpha value for the second transition of the lower contour was due to few ratings.

Perceived break, no.	Cronbach´s alpha, a
Upper contour; 1	.77
Lower contour; 1	.88
Upper contour; 2	.80
Lower contour; 2	(.47)

Table 1. Interjudge reliability coeffients for ratings of the location of the first and second register transitions in the lower and upper contour. Numbers refer to register transitions.

The mean intrajudge reliability as determined by Pearson's correlation coefficient was .72, thus indicating a reasonable degree of consistency within the judges, see Table 2. Since the panel members in most cases did not detect a second register transition in the lower VRP contour, the intrajudge reliability coefficient could not be computed in this case.

Table 2. Mean intrajudge reliability coefficients, standard deviations and ranges based on the repeated ratings of 5 voices by five listeners across the location of the first and second voice transition in the lower and upper contour. N equals number of listeners who perceived a transition on both presentations. Due to few replicated observations of a second transition in the lower contour no correlation coefficient could be calculated.

Perceived break, no.	Mean Pearson corr coeff.	Std Dev	Minimum	Maximum	N
Upper contour; 1	67,3	22,6	33,6	92,6	5
Lower contour; 1	65,6	9,3	57,1	75,6	3
Upper contour; 2	83,1	23,9	66,2	100,0	2
Lower contour; 2					

The panel members observed one or two register transitions in each contour for each voice. Surprisingly, the listeners were equally successful in perceiving the first transition in loud as in soft singing. This transition was mostly observed at approximately the same pitch level in both contours.

The mean voice range for the whole group was 27 semitones, ranging from 185 Hz, (F#3), to 880 Hz, (A5). The mean frequency for the first register transition was 466 Hz, (Bb4).

As illustrated in Figure 1, the children with functional or physiological voice deviations - i.e. chronic hoarseness, vocal nodules and glottal chinks - showed one register transition only, mean frequency 415 Hz - (G#4). The first register transition for the control children occurred at 494 Hz, (B4) and at 554 Hz, (C#5) for the mutational voices. A second transition was consistently observed only for the controls and for the mutational voices at a mean frequency of 831 Hz (Ab5) and 988 Hz (B6), respectively.

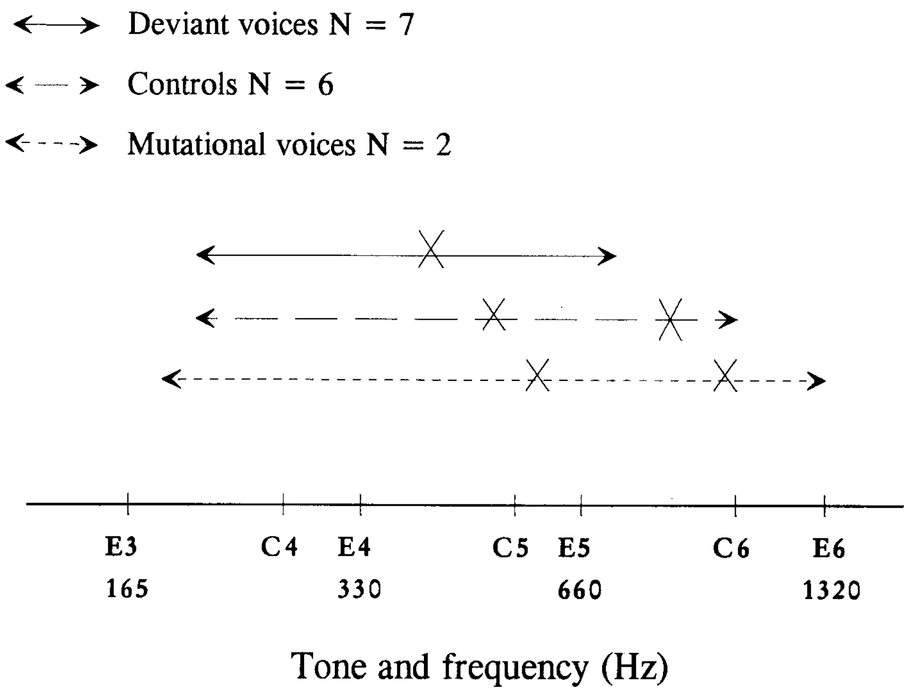

Figure 1. Register transitions for three groups of voices.

Adopting the ideas of Pedersen et al. (1984) all register transitions were correlated to VRP contour discontinuities exceeding 5 dB between two data points. The scatter plot shown in Fig. 2 revealed no correlation. The discontinuity chosen was closest to the perceived register transition. If the criterion for a discontinuity had been a 3 dB change rather than 5 dB, the covariation would have been somewhat higher. As mentioned, Klingholz and Martin (1983) proposed a method to locate register transitions from descriptions of the VRP by means of ellipses while Klingholz et al. (1985) used contour discontinuities as the criterion. Due to different correction curves for the SPL measurement, data cannot easily be compared to ours. The data shown in Figure 2 suggest that this criterion is not useful in the case of these children's voices, although a better accordance may have emerged with a denser sampling of SPL data along the pitch axis.

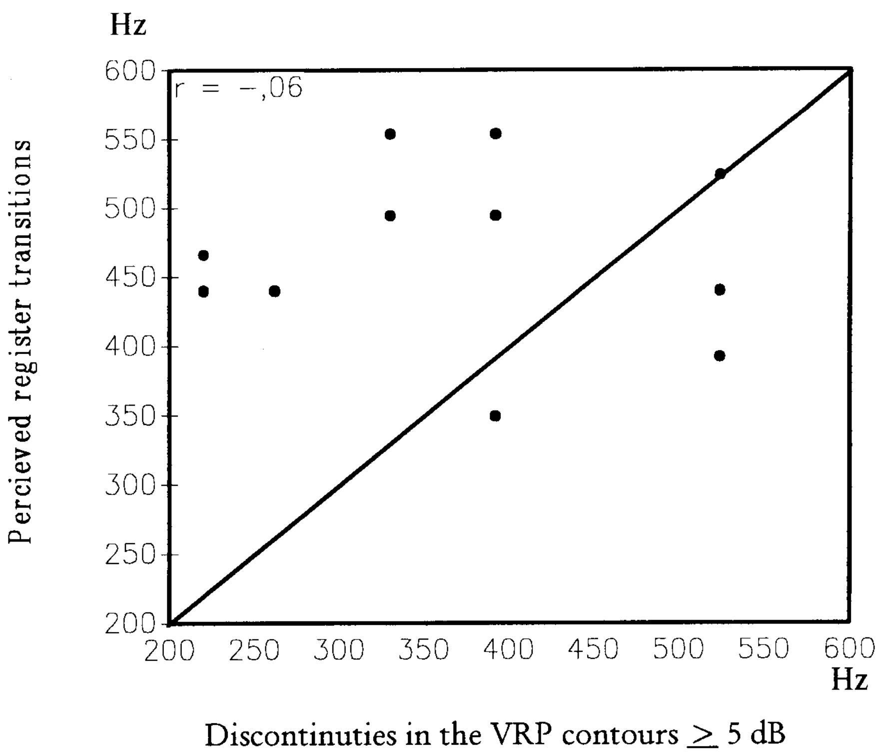

Figure 2. Perceived register transitions related to the closest discontinuity in the VRP contours ≥ 5dB. This transaction could only be performed for the voices with a perceived register transition, N= 11.

DISCUSSION

According to Titze (1988), register transitions depend on sub- and supraglottal resonances. The pitch at which the main register transitions occur can be calculated from the length of the trachea. Titze predicts that reinforcement of vocal fold vibration is achieved when the subglottal pressure is positive during the opening and negative during the closing phase. If the tracheal resonance returns the reflection of the glottal pulse out of phase with the glottal vibration, a register transition is likely to occur. In the case of adults, register transitions can be predicted at 260 - 500 Hz depending on tracheal length. In our group of children the first register transition varied between 350 and 600 Hz, or 25 % higher. According to growth index for Swedish children, ten-year-old children are approximately 25% shorter than the adult average (Karlberg et al., 1976). If tracheal length differs accordingly, our results are in good agreement with Titze's model.

CONCLUSIONS

Two register transitions could be detected in ten-year-old childrens´ voices close to 466 and 831 Hz, respectively. The first of these appeared in both soft and loud phonation. However, only one transition was observed in children with chronic hoarseness, vocal nodules, and glottal chinks. No relation was found between these frequencies and discontinuities in the VRP contours. The frequency for the lower transition was in accordance with the model for vocal registers proposed by Titze (1988).

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